View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Kazan Federal University Digital Repository

Physical Review D 2018 vol.98 N4

Inflation in an effective gravitational model and asymptotic safety

Liu L., Prokopec T., Starobinsky A.

Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2018 American Physical Society. We consider an inflationary model motivated by quantum effects of gravitational and matter fields near the Planck scale. Our Lagrangian is a resummed version of the effective Lagrangian recently obtained by Demmel, Saueressig, and Zanusso [A proper fixed functional for four-dimensional quantum Einstein gravity, J. High Energy Phys. 08 (2015) 113.JHEPFG1029-847910.1007/JHEP08(2015)113] in the context of gravity as an asymptotically safe theory. It represents a refined Starobinsky model, Leff=MP2R/2+(a/2)R2/[1+bln(R/μ2)], where R is the Ricci scalar, a and b are constants, and μ is an energy scale. By implementing the COBE normalization and the Planck constraint on the scalar spectrum, we show that increasing b leads to an increased value of both the scalar spectral index ns and the tensor-to-scalar ratio r. Requiring ns to be consistent with the Planck Collaboration upper limit, we find that r can be as large as r≃0.01, the value possibly measurable by Stage IV CMB ground experiments and certainly from future dedicated space missions. The predicted running of the scalar spectral index α=dns/dln(k) is still of the order -5×10-4 (as in the Starobinsky model), about 1 order of magnitude smaller than the current observational bound.

http://dx.doi.org/10.1103/PhysRevD.98.043505

References

[1] A. A. Starobinsky, Spectrum of relict gravitational radiation and the early state of the universe, Pis'ma Zh. Eksp. Teor. Fiz. 30, 719 (1979) PZETAB 0370-274X

[2] [A. A. Starobinsky JETP Lett. 30, 682 (1979)]. JTPLA2 0021-3640

[3] A. A. Starobinsky, A new type of isotropic cosmological models without singularity, Phys. Lett. B 91, 99 (1980). PYLBAJ 0370-2693 10.1016/0370-2693(80)90670-X

[4] A. H. Guth, The inflationary universe: A possible solution to the horizon and flatness problems, Phys. Rev. D 23, 347 (1981). PRVDAQ 0556-2821 10.1103/PhysRevD.23.347

[5] A. D. Linde, A new inflationary universe scenario: A possible solution of the horizon, flatness, homogeneity, isotropy and primordial monopole problems, Phys. Lett. B 108, 389 (1982). PYLBAJ 0370-2693 10.1016/0370-2693(82)91219-9

[6] J. F. Donoghue, General relativity as an effective field theory: The leading quantum corrections, Phys. Rev. D 50, 3874 (1994). PRVDAQ 0556-2821 10.1103/PhysRevD.50.3874

[7] P. A. R. Ade (Planck Collaboration), Planck 2015 results. XX. Constraints on inflation, Astron. Astrophys. 594, A20 (2016). AAEJAF 0004-6361 10.1051/0004-6361/201525898

[8] A. A. Starobinsky, Nonsingular model of the Universe with the quantum-gravitational de Sitter stage and its observational consequences, in Proceedings of the Second Seminar, Quantum Theory of Gravity (Moscow, 1981) (INR Press, Moscow, 1982), p. 58;

[9] reprinted in Quantum Gravity, edited by M. A. Markov and P. C. West (Plenum, New York, 1984), p. 103.

[10] K. P. Stanyukovich, Gravitational Field and Elementary Particles [(Gravitatsionnoie pole i elementarnyie chastitsy] (Nauka, Moscow, 1965).

[11] B. S. DeWitt, Quantum theory of gravity. 1. The canonical theory, Phys. Rev. 160, 1113 (1967). PHRVAO 0031-899X 10.1103/PhysRev.160.1113

[12] B. S. DeWitt, Quantum theory of gravity. 3. Applications of the covariant theory, Phys. Rev. 162, 1239 (1967). PHRVAO 0031-899X 10.1103/PhysRev.162.1239

[13] V. L. Ginzburg, D. A. Kirzhnits, and A. A. Lyubushin, The role of quantum fluctuations of the gravitational field in general relativity and cosmology, Zh. Eksp. Teor. Fiz. 60, 451 (1971) ZETFA7 0044-4510

[14] [V. L. Ginzburg, D. A. Kirzhnits, and A. A. Lyubushin Sov. Phys. JETP 33, 242 (1971)]. SPHJAR 0038-5646

[15] Ya. B. Zeldovich and A. A. Starobinsky, Particle production and vacuum polarization in an anisotropic gravitational field, Zh. Eksp. Teor. Fiz. 61, 2161 (1971) ZETFA7 0044-4510

[16] [Ya. B. Zeldovich and A. A. Starobinsky Sov. Phys. JETP 34, 1159 (1972)]. SPHJAR 0038-5646

[17] G. 't Hooft and M. J. G. Veltman, One loop divergences in the theory of gravitation, Ann. Inst. Henri Poincaré, A 20, 69 (1974).

[18] M. H. Goroff and A. Sagnotti, Quantum gravity at two loops, Phys. Lett. B 160, 81 (1985). PYLBAJ 0370-2693 10.1016/0370-2693(85)91470-4

[19] A. E. M. van de Ven, Two loop quantum gravity, Nucl. Phys. B378, 309 (1992). NUPBBO 0550-3213 10.1016/0550-3213(92)90011-Y

[20] S. Weinberg, Critical Phenomena for Field Theorists (Spinger, New Yorlk, 1979).

[21] S. Weinberg, in General Relativity: An Einstein Centenary Survey, edited by S. W Hawking and W. Israel (Cambridge University Press, Cambridge, England, 1979), p. 790.

[22] S. Weinberg, Effective field theory, past and future, Int. J. Mod. Phys. A 31, 1630007 (2016). IMPAEF 0217-751X 10.1142/S0217751X16300076

[23] S. Weinberg, Effective field theory, past and future, Proc. Sci., CD09 (2009) 001, arXiv:0908.1964.

[24] M. Reuter, Nonperturbative evolution equation for quantum gravity, Phys. Rev. D 57, 971 (1998). PRVDAQ 0556-2821 10.1103/PhysRevD.57.971

[25] M. Reuter and F. Saueressig, Quantum Einstein gravity, New J. Phys. 14, 055022 (2012). NJOPFM 1367-2630 10.1088/1367-2630/14/5/055022

[26] M. Demmel, F. Saueressig, and O. Zanusso, A proper fixed functional for four-dimensional quantum Einstein gravity, J. High Energy Phys. 08 (2015) 113. JHEPFG 1029-8479 10.1007/JHEP08(2015)113

[27] C. Fang and Q. G. Huang, The trouble with asymptotically safe inflation, Eur. Phys. J. C 73, 2401 (2013). EPCFFB 1434-6044 10.1140/epjc/s10052-013-2401-2

[28] Q.-G. Huang, A polynomial f(R) inflation model, J. Cosmol. Astropart. Phys. 02 (2014) 035. JCAPBP 1475-7516 10.1088/1475-7516/2014/02/035

[29] A. Marunović and T. Prokopec, Planck scale operators, inflation and fine tuning, Phys. Rev. D 96, 043512 (2017). PRVDAQ 2470-0010 10.1103/PhysRevD.96.043512

[30] M. Reuter and F. Saueressig, From big bang to asymptotic de Sitter: Complete cosmologies in a quantum gravity framework, J. Cosmol. Astropart. Phys. 09 (2005) 012. JCAPBP 1475-7516 10.1088/1475-7516/2005/09/012

[31] A. Bonanno and M. Reuter, Cosmology of the Planck era from a renormalization group for quantum gravity, Phys. Rev. D 65, 043508 (2002). PRVDAQ 0556-2821 10.1103/PhysRevD.65.043508

[32] A. Bonanno and M. Reuter, Cosmology with self-adjusting vacuum energy density from a renormalization group fixed point, Phys. Lett. B 527, 9 (2002). PYLBAJ 0370-2693 10.1016/S0370-2693(01)01522-2

[33] A. Bonanno, A. Contillo, and R. Percacci, Inflationary solutions in asymptotically safe f(R) theories, Classical Quantum Gravity 28, 145026 (2011). CQGRDG 0264-9381 10.1088/0264-9381/28/14/145026

[34] K. Falls, D. F. Litim, K. Nikolakopoulos, and C. Rahmede, On de Sitter solutions in asymptotically safe (Equation presented) theories, Classical Quantum Gravity 35, 135006 (2018). CQGRDG 0264-9381 10.1088/1361-6382/aac440

[35] S. Weinberg, Asymptotically safe inflation, Phys. Rev. D 81, 083535 (2010). PRVDAQ 1550-7998 10.1103/PhysRevD.81.083535

[36] S.-H. H. Tye and J. Xu, Comment on asymptotically safe inflation, Phys. Rev. D 82, 127302 (2010). PRVDAQ 1550-7998 10.1103/PhysRevD.82.127302

[37] M. Hindmarsh, D. Litim, and C. Rahmede, Asymptotically safe cosmology, J. Cosmol. Astropart. Phys. 07 (2011) 019. JCAPBP 1475-7516 10.1088/1475-7516/2011/07/019

[38] A. Bonanno and F. Saueressig, Asymptotically safe cosmology-A status report, C.R. Phys. 18, 254 (2017). CRPOBN 1631-0705 10.1016/j.crhy.2017.02.002

[39] Y. F. Cai and D. A. Easson, Asymptotically safe gravity as a scalar-tensor theory and its cosmological implications, Phys. Rev. D 84, 103502 (2011). PRVDAQ 1550-7998 10.1103/PhysRevD.84.103502

[40] E. J. Copeland, C. Rahmede, and I. D. Saltas, Asymptotically safe Starobinsky inflation, Phys. Rev. D 91, 103530 (2015). PRVDAQ 1550-7998 10.1103/PhysRevD.91.103530

[41] A. Codello, J. Joergensen, F. Sannino, and O. Svendsen, Marginally deformed Starobinsky gravity, J. High Energy Phys. 02 (2015) 50. JHEPFG 1029-8479 10.1007/JHEP02(2015)050

[42] K. Bamba, G. Cognola, S. D. Odintsov, and S. Zerbini, One-loop modified gravity in a de Sitter universe, quantum-corrected inflation, and its confrontation with the Planck result, Phys. Rev. D 90, 023525 (2014). PRVDAQ 1550-7998 10.1103/PhysRevD.90.023525

[43] I. Ben-Dayan, S. Jing, M. Torabian, A. Westfal, and L. Zarate, (Equation presented) quantum corrections and the inflationary observables, J. Cosmol. Astropart. Phys. 09 (2014) 005. JCAPBP 1475-7516 10.1088/1475-7516/2014/09/005

[44] A. Bonanno and A. Platania, Asymptotically safe inflation from quadratic gravity, Phys. Lett. B 750, 638 (2015). PYLBAJ 0370-2693 10.1016/j.physletb.2015.10.005

[45] M. Rinaldi, G. Cognola, L. Vanzo, and S. Zerbini, Reconstructing the inflationary (Equation presented) from observations, J. Cosmol. Astropart. Phys. 08 (2014) 015. JCAPBP 1475-7516 10.1088/1475-7516/2014/08/015

[46] S. R. Coleman and E. J. Weinberg, Radiative corrections as the origin of spontaneous symmetry breaking, Phys. Rev. D 7, 1888 (1973). PRVDAQ 0556-2821 10.1103/PhysRevD.7.1888

[47] N. Alkofer and F. Saueressig, Asymptotically safe (Equation presented)-gravity coupled to matter I: the polynomial case, arXiv:1802.00498.

[48] V. T. Gurovich and A. A. Starobinsky, Quantum effects and regular cosmological models, Sov. Phys. JETP 50, 844 (1979). SPHJAR 0038-5646

[49] G. K. Chakravarti and S. Mohanty, Power law Starobinsky model of inflation from no-scale SUGRA, Phys. Lett. B 746, 242 (2015). PYLBAJ 0370-2693 10.1016/j.physletb.2015.04.056

[50] H. Motohashi, Consistency relation for (Equation presented) inflation, Phys. Rev. D 91, 064016 (2015). PRVDAQ 1550-7998 10.1103/PhysRevD.91.064016

[51] L. H. Liu, Analysis of (Equation presented) inflationary model as (Equation presented), arXiv:1807.00666.

[52] M. Rinaldi, G. Cognola, L. Vanzo, and S. Zerbini, Inflation in scale-invariant theories of gravity, Phys. Rev. D 91, 123527 (2015). PRVDAQ 1550-7998 10.1103/PhysRevD.91.123527

[53] N. Palanque-Delabrouille, Cosmology with Lyman-alpha forest power spectrum, J. Cosmol. Astropart. Phys. 11 (2015) 011. JCAPBP 1475-7516 10.1088/1475-7516/2015/11/011

[54] P. A. R. Ade (BICEP2 and Planck Collaborations), Joint Analysis of (Equation presented) and Planck Data, Phys. Rev. Lett. 114, 101301 (2015). PRLTAO 0031-9007 10.1103/PhysRevLett.114.101301

[55] P. A. R. Ade (BICEP2 and Keck Array Collaborations), Improved Constraints on Cosmology and Foregrounds from BICEP2 and Keck Array Cosmic Microwave Background Data with Inclusion of 95 GHz Band, Phys. Rev. Lett. 116, 031302 (2016). PRLTAO 0031-9007 10.1103/PhysRevLett.116.031302

[56] Y. Akrami (Planck Collaboration), Planck 2018 results. X. Constraints on inflation, arXiv:1807.06211.

[57] F. R. Bouchet (COrE Collaboration), COrE (Cosmic Origins Explorer) A White Paper, arXiv:1102.2181.

[58] T. Matsumura, Mission design of LiteBIRD, J. Low Temp. Phys. 176, 733 (2014). JLTPAC 0022-2291 10.1007/s10909-013-0996-1

[59] S. A. Appleby, R. A. Battye, and A. A. Starobinsky, Curing singularities in cosmological evolution of (Equation presented) gravity, J. Cosmol. Astropart. Phys. 06 (2010) 005. JCAPBP 1475-7516 10.1088/1475-7516/2010/06/005

[60] A. A. Starobinsky, Dynamics of phase transition in the new inflationary Universe scenario and generation of perturbations, Phys. Lett. B 117, 175 (1982). PYLBAJ 0370-2693 10.1016/0370-2693(82)90541-X

[61] A. A. Starobinsky, The perturbation spectrum evolving from a nonsingular, initially de Sitter cosmology, and the microwave background anisotropy, Pisma v Astron. Zh. 9, 579 (1983) SALEDW 0360-0327

[62] [A. A. Starobinsky Sov. Astron. Lett. 9, 302 (1983)].

[63] L. A. Kofman and V. F. Mukhanov, Evolution of perturbations in an inflationary universe, Pis'ma Zh. Eksp. Teor. Fiz. 44, 481 (1986) PZETAB 0370-274X

[64] [L. A. Kofman and V. F. Mukhanov JETP Lett. 44, 619 (1986)]. JTPLA2 0021-3640

[65] V. F. Mukhanov and G. V. Chibisov, Quantum fluctuations and a non-singular universe, Pis'ma Zh. Eksp. Teor. Fiz. 33, 549 (1981) PZETAB 0370-274X

[66] [V. F. Mukhanov and G. V. Chibisov JETP Lett. 33, 532 (1981)]. JTPLA2 0021-3640

[67] J.-C. Hwang and H. Noh, Cosmological perturbations in generalized gravity theories, Phys. Rev. D 54, 1460 (1996). PRVDAQ 0556-2821 10.1103/PhysRevD.54.1460